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STATISTICAL ANALYSIS OF LANDING CONTACT CONDITIONS OF THE X-15 AIRPLANE

by Ronald J. Wilson

Flight Research Center
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SUMMARY

The landing contact conditions and slideout distances for 135 landings of the X-15 research airplane are discussed. The conditions are similar to those that might be experienced by future lifting-body reentry vehicles or other flight vehicles with low lift-drag ratios.

Results are presented in the form of histograms for frequency distributions, and Pearson Type III probability curves for the landing contact conditions of vertical velocity, calibrated airspeed, true ground speed, rolling velocity, roll angle, distance from intended touchdown point, and slideout distance. Additional statistical parameters presented for each of the described conditions are the mean, standard deviation, and the coefficient of skewness.

INTRODUCTION

Statistical studies of landing conditions just prior to ground contact for both military and commercial aircraft have been presented in numerous reports, for example, references 1 to 3. These studies are useful to the designer in assessing landing-load requirements and in the design of runways.

In recent years intensified studies have been made of the aerodynamic, structural, and operational characteristics of lifting bodies that may be used as piloted reentry vehicles. Advantages offered by this type of vehicle are low reentry heating rates and a large reentry footprint that would enable a pilot to select his landing site. Associated studies have been made of landing contact conditions for vehicles with low lift-drag ratios (refs. 4 and 5) in order to assess landing-load requirements. These landing studies can best be supplemented by statistical analyses of actual landing experience with flight vehicles of this type. To provide such information, analyses were made of landings of the X-15 airplane, since the X-15 is the only low lift-drag-ratio, skid-equipped research vehicle with a sufficient number of recorded landings to permit statistical analyses of the data. The results of the analyses are presented in this paper in terms of vertical velocity, calibrated airspeed, true ground speed, rolling velocity, roll angle, touchdown distance from intended touchdown point, and slideout distance. The data were obtained

from 135 landings of the X-15 airplane following research flights from the NASA Flight Research Center at Edwards, Calif.

Measurements were taken in U. S. Customary Units; equivalent values in the International System of Units (SI) are added throughout the paper. Details on SI, together with physical constants and conversion factors, are given in reference 6.

AIRPLANE DESCRIPTION AND LANDING CONDITIONS

The X-15 airplane is described in detail in reference 4. Briefly, the vehicle (fig. 1) is a rocket-powered research aircraft capable of attaining a Mach number of 6 and an altitude in excess of 300,000 feet (91,440 meters). The landing-gear system consists of a nonsteerable, full-castering nose gear located well forward of the airplane's center of gravity and skid-type, articulated main gear located well to the rear under the tail.

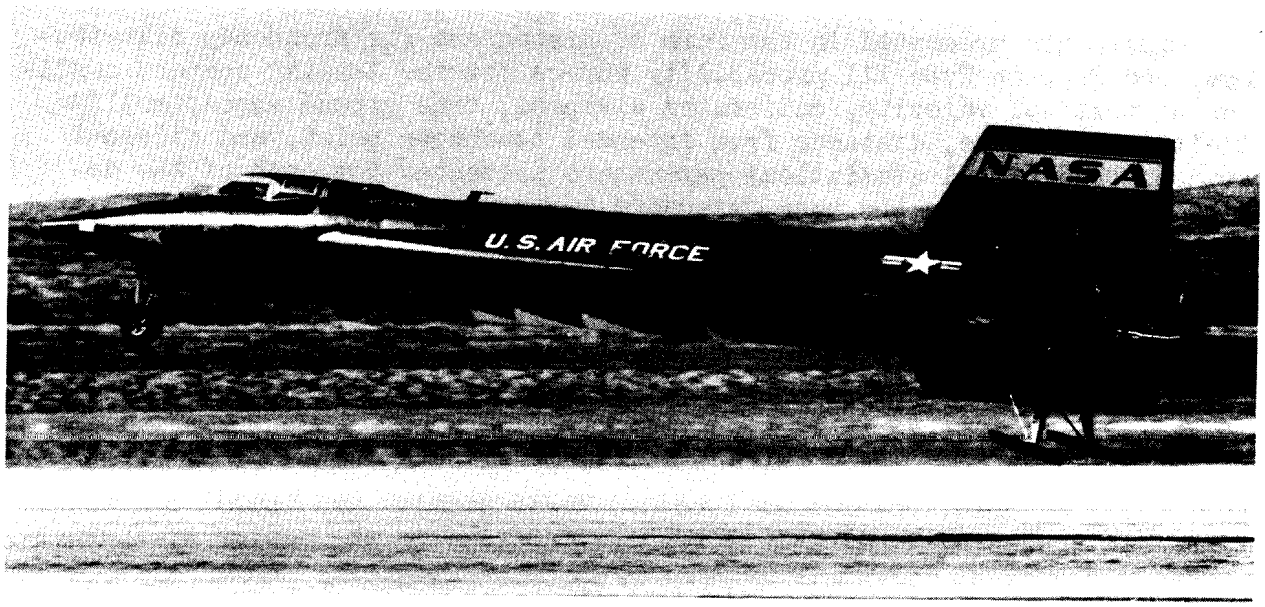


Figure 1.— X-15 research airplane.

The landing conditions described herein are considered to be representative of landing conditions experienced by gliding, low lift-drag-ratio vehicles. Eleven pilots were used in the 135 flights: five NASA, four Air Force, one Navy, and one North American Aviation, Inc.

All of the landings except four were made on the smooth, hard surface of Rogers Dry Lake at Edwards, Calif. Four emergency landings were made on other lakebed surfaces. A tar strip at least 3 miles (4828 meters) long was laid out on all lakebeds for pilot reference. At the intended touchdown point, a smoke bomb was released to give the pilot a visual landing reference and a check on wind conditions.

Typically, a flare was initiated at an altitude of about 800 feet (244 meters) and at an indicated airspeed of approximately 300 knots. The lift-drag ratio at this condition is 3.2, as shown in figure 2, which is reproduced from reference 7. Lowering the flaps changed the lift-drag ratio to 2.8 to 3.0 as the airspeed decreased. A few seconds later the gear was lowered. Speed continued to decrease, accompanied by an increase in lift-drag ratio to 3.3 at a touchdown speed of 200 knots. On several occasions, speed brakes were used in the final flare. For this type of landing approach, the lift-drag ratio varied from 1.9 to 2.5.

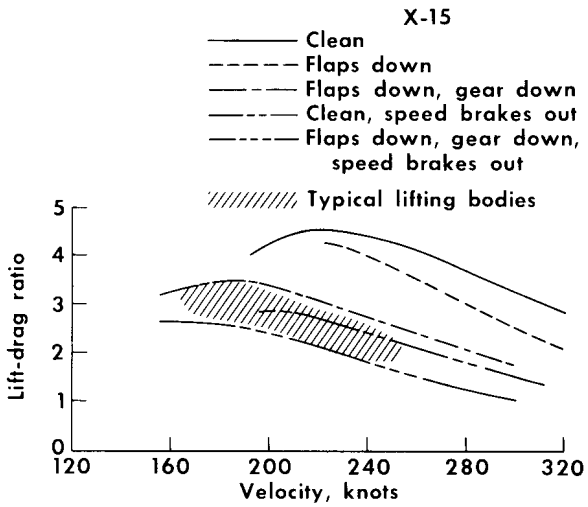


Figure 2.– Variation of lift-drag ratio with velocity for various X-15 configurations and lifting bodies (adapted from ref. 7).

INSTRUMENTATION AND DATA REDUCTION

Such pertinent quantities as airspeed, roll angle, and roll velocity were recorded on NASA internal recording instruments. Data for calibrated airspeed (for convenience, referred to hereafter as airspeed) were obtained from impact-pressure measurements on the flow-direction sensor in the nose of the aircraft and from static-pressure pickups on the aircraft fuselage. Roll rate and roll angle were obtained by use of rate and attitude gyros, respectively. The measured quantities were recorded on standard oscillographs, synchronized at 0.1-second intervals by a common timer. The natural frequency and damping ratio of the recording galvanometers were 20 cps and 0.64, respectively. Recordings were accurate within ±2 percent of full-scale readings.

Vertical velocity at touchdown was first obtained by phototheodolite cameras and by a velocity switch installed on the X-15 skid. As sufficient data became available, the imprint of the main-gear tread on the lakebed during the first reaction (fig. 3) was correlated with the vertical velocity at touchdown. From the correlation it was determined that the vertical velocity could be predicted by the gear-tread measurements within ±0.25 ft/sec (0.076 m/sec). After the first 38 landings, vertical velocity was determined by measuring main-gear tread.

True ground speed at touchdown was calculated by dividing the measured distance between the main-gear and nose-gear touchdown points on the lakebed by the time interval between main-gear and nose-gear touchdown as obtained from oscillograph records. The data are accurate within ±1 knot.

RESULTS AND DISCUSSION

Landing contact conditions for the first 135 landings of the X-15 airplane are summarized in table I. Omissions in the table result from system failures,

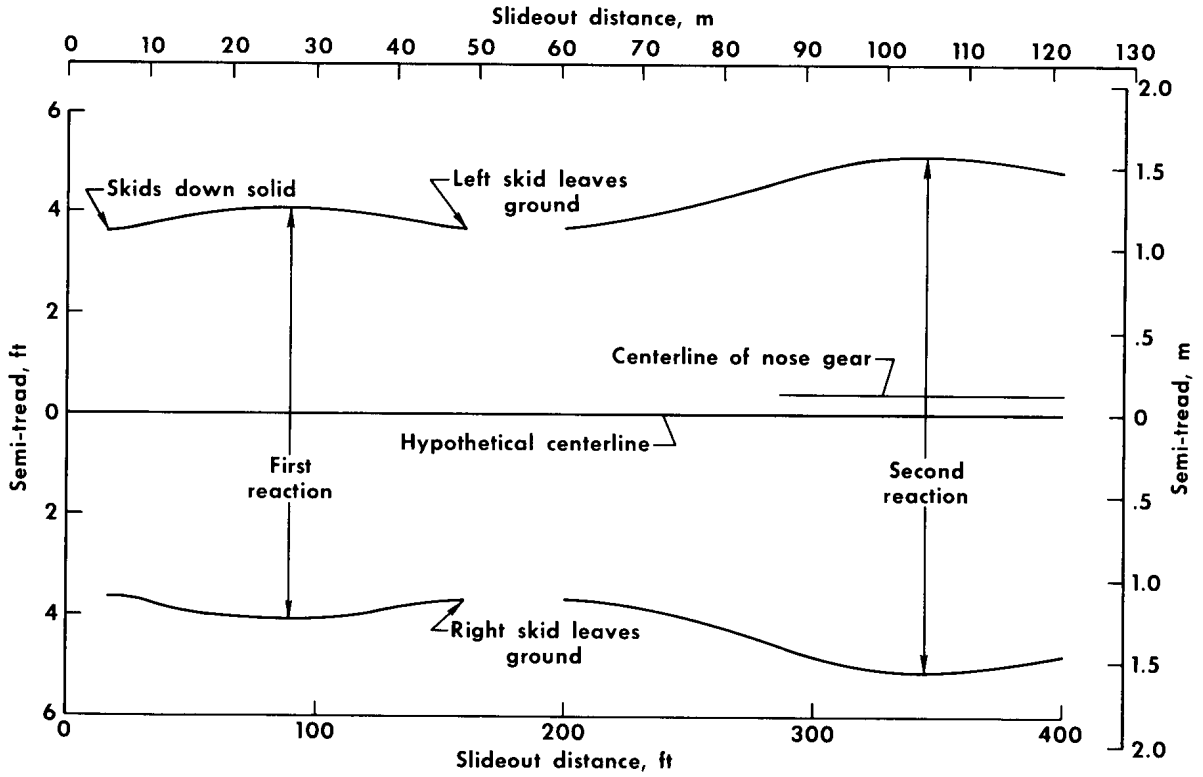


Figure 3.— Main-gear-tread skid marks on lakebed for the touchdown phase.

instrumentation malfunctions, and emergency conditions. The four emergency landings are noted.

The landing data were analyzed statistically by using the following procedure: Pearson Type III curves were fitted to the data to provide a systematic fairing and a mathematical basis for extrapolation. The computed curves were then compared with the observed results. Values of the statistical parameters (mean value, standard deviation, and coefficient of skewness) used in the determination of the Pearson curves are listed in table II. Details of the computation process are given in the appendix. Results of the computations are presented in figures 4 to 17 as histograms and probability curves.

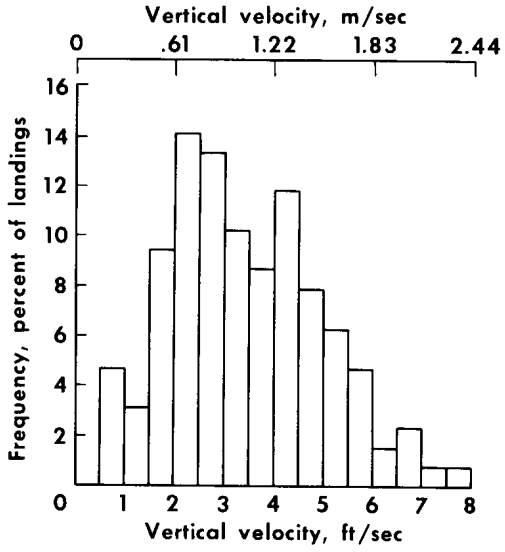


Figure 4.— Histogram of vertical velocity at touchdown.

Vertical Velocity

Figure 4 shows the frequency distribution of vertical velocity at touchdown in percent of landings occurring in class intervals of 0.5 ft/sec (0.15 m/sec). For the greatest number of landings, 14.2 percent, vertical velocity was in the interval of 2.0 ft/sec to 2.5 ft/sec (0.61 m/sec to

0.76 m/sec); whereas, in only 0.8 percent of the landings a vertical velocity of 7.5 ft/sec to 8.0 ft/sec (2.29 m/sec to 2.44 m/sec) was attained. The mean vertical velocity for the 135 landings was 3.4 ft/sec (1.04 m/sec).

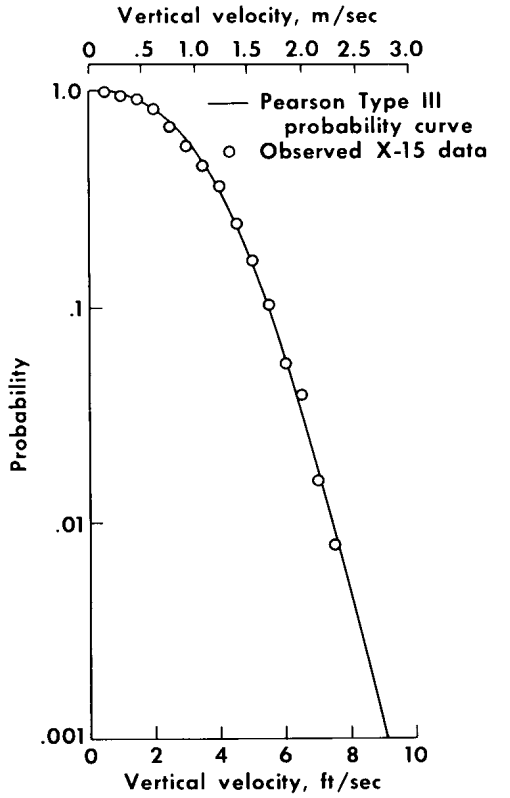


Figure 5.– Probability of equaling or exceeding various vertical velocities during landing contact.

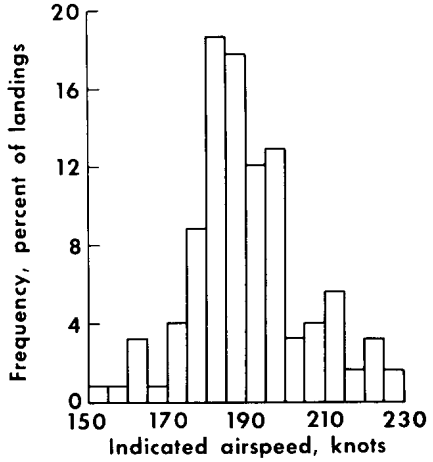


Figure 6.– Histogram of airspeed at contact.

Figure 5 shows the probability of equaling or exceeding given values of vertical velocity. The vertical velocity at a probability of 0.01 is 7.4 ft/sec (2.27 m/sec), which is the rate of descent that will probably be equaled or exceeded once in every 100 landings. A probability of 0.01 was selected because it represented a fairly low probability which, at the same time, required little extrapolation of the data in the sample. One landing (flight 2-3-9) was made at a vertical velocity of 9.5 ft/sec (2.90 m/sec) under emergency conditions and, thus, was not considered a normal landing.

Airspeed

The frequency distribution of airspeed at touchdown, in percent of landings, is presented in figure 6 in class intervals of 5 knots. The greatest number of landings, 18.7 percent, occurred in the interval from 180 knots to 185 knots, while only 1.6 percent were made at airspeeds between 225 knots and 230 knots. Mean airspeed was 190.5 knots. The probability distribution of airspeed (fig. 7) shows that 1 landing in 100 would be likely to equal or exceed 228 knots. The emergency landing on flight 2-31-52 was made at a touchdown airspeed of 251 knots with flaps up and the airplane in an overweight condition and, therefore, was not considered a probable case for this analysis.

True Ground Speed

The frequency distribution of true ground speed at touchdown occurring in

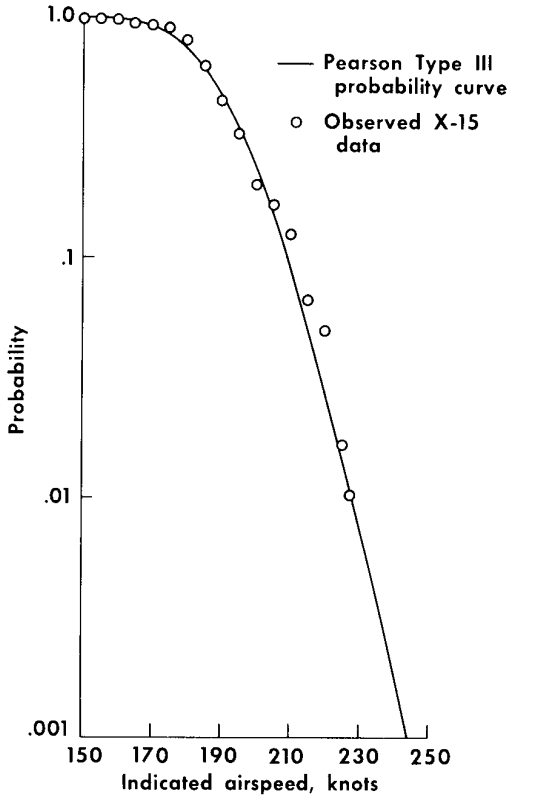


Figure 7.– Probability of equaling or exceeding various indicated airspeeds at contact.

class intervals of 5 knots (fig. 8) indicates that the greatest percentage (12.2) of the landings occurred in the interval from 195 knots to 200 knots. The mean was 193.0 knots. The probability distribution of true ground speed (fig. 9) shows that 1 landing in 100 would be likely to equal or exceed 234 knots. The landing for flight 2-31-52, described in the preceding discussion of airspeed, was made at a true ground speed of 256 knots but was not considered a probable case for this analysis.

Aircraft Rolling Velocity

Rolling velocities are presented as rolling either toward or away from the first skid to touch the runway. The frequency distributions of figures 10(a) and 10(b) indicate that most of the rolling velocities were between

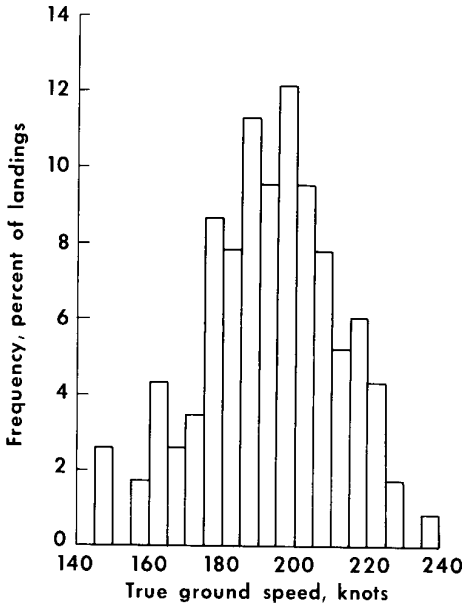


Figure 8.– Histogram of true ground speed at contact.

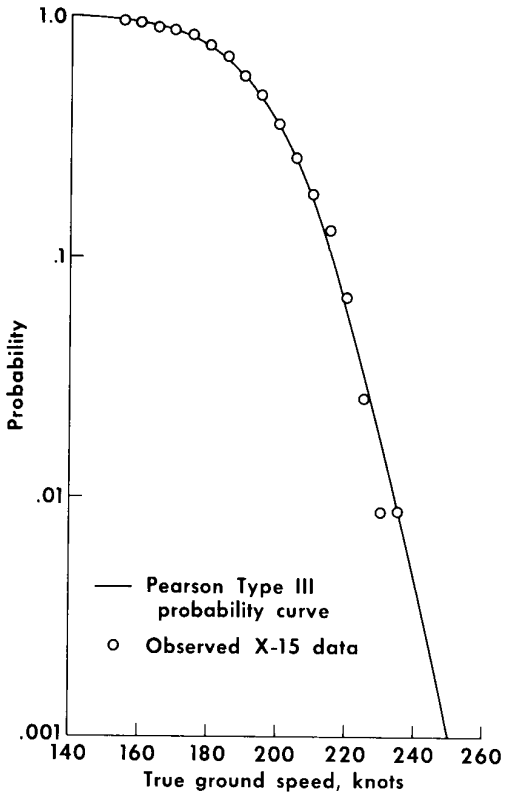
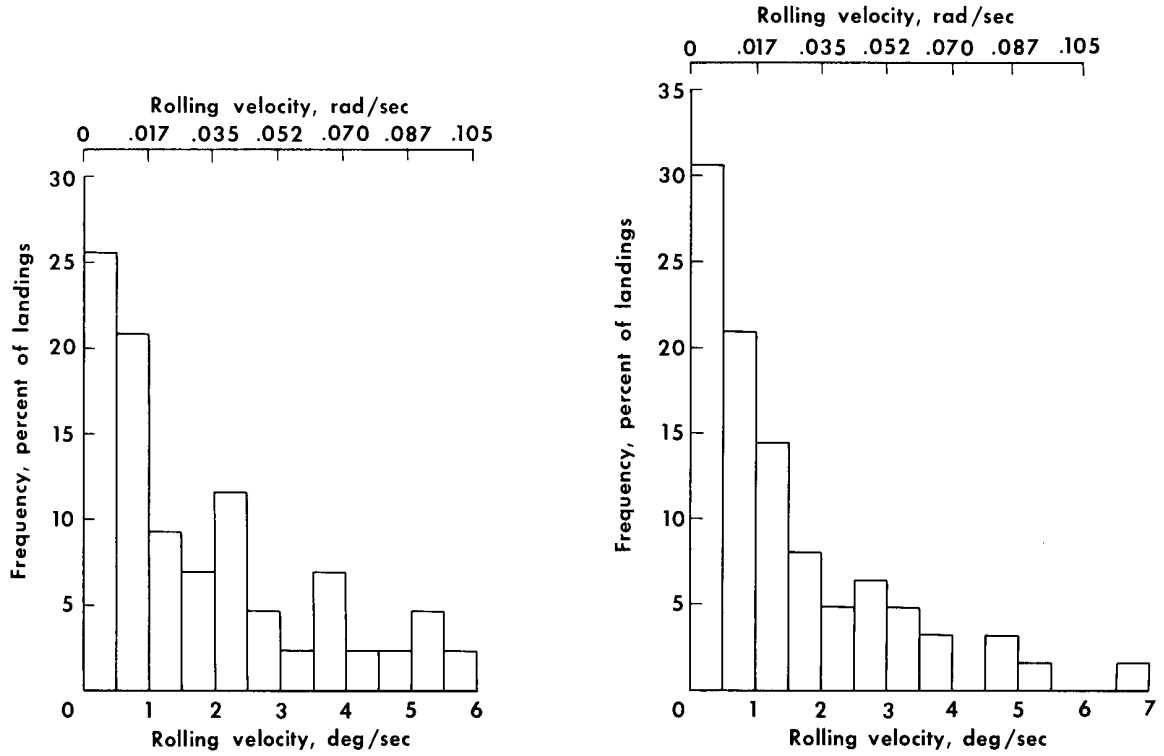


Figure 9.– Probability of equaling or exceeding various ground speeds at contact.



(a) Toward first skid to contact.

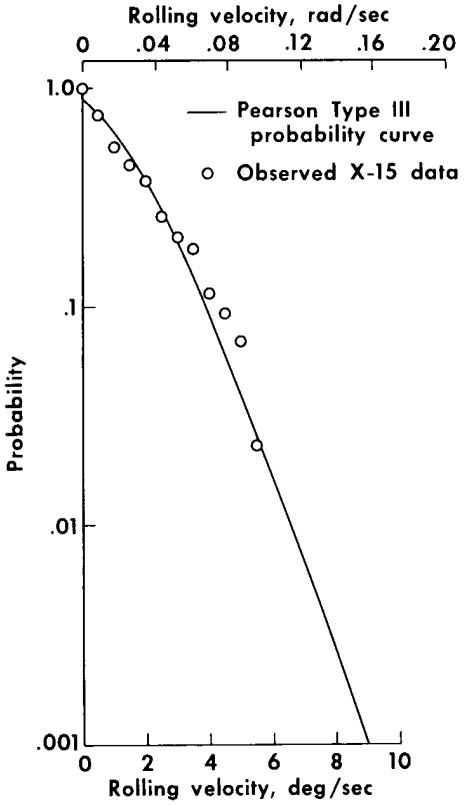
(b) Away from first skid to contact.

Figure 10.– Histogram of rolling velocity at touchdown.

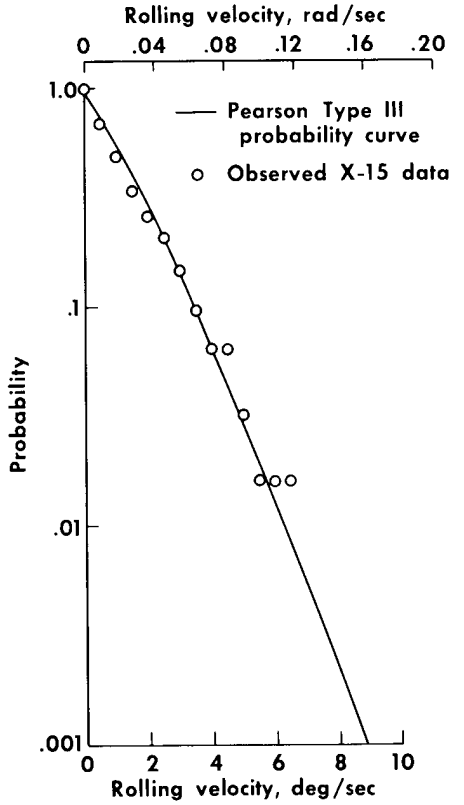
0 and 0.5 deg/sec (0.009 rad/sec), either toward or away from the first skid to contact. The highest percentage of rolling velocities (30.6) falls in the range of 0 to 0.5 deg/sec (0.009 rad/sec) away from first contact. In the greatest number of landings (62) the rolling velocity was away from first contact; in 43 landings, rolling velocities were toward first contact. The mean rolling velocity was 1.77 deg/sec (0.031 rad/sec) toward the first skid to contact, and 1.47 deg/sec (0.026 rad/sec) away from the first skid to contact. The probability distributions (figs. 11(a) and 11(b)) indicate that in 1 landing out of 100 rolling velocity would be expected to equal or exceed 6.6 deg/sec (0.114 rad/sec) toward the first skid to contact and 6.3 deg/sec (0.110 rad/sec) away from the first skid to contact.

Roll Angle

The frequency distribution of the absolute roll angle at touchdown (fig. 12) shows that the greatest percentage of landings (22.9) occurred in the interval from 1.0° to 1.5° (0.017 rad to 0.026 rad). The mean roll angle was 1.4° (0.024 rad). The probability distribution of roll angle (fig. 13) indicates that 1 landing in 100 would be likely to equal or exceed 3.92° (0.068 rad).



(a) Toward first skid to contact.



(b) Away from first skid to contact.

Figure 11.— Probability of equaling or exceeding various values of rolling velocity at touchdown.

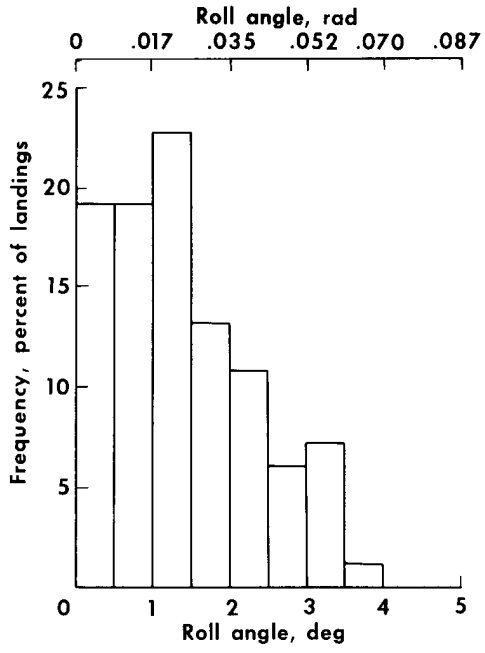


Figure 12.— Histogram of absolute roll angle at touchdown.

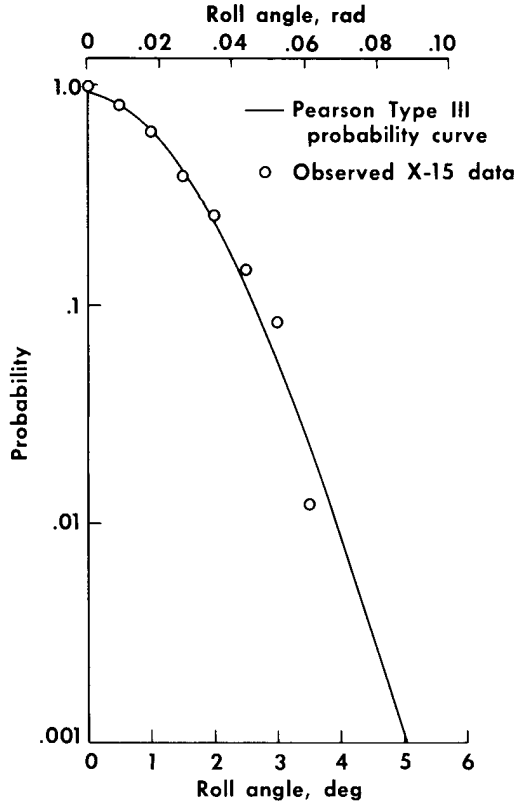


Figure 13.— Probability of equaling or exceeding various roll angles at touchdown.

Distance to Touchdown Point

The landings included in this analysis took place on the same runway, with the intended touchdown point at the 2-mile (3219-meter) marker. During X-15 landings, a smoke bomb is released at the 2-mile point to serve as a reference point for the pilot and as a windage indicator. For a number of landings, pilots were assigned the task of landing as near as possible to the 2-mile marker. For this analysis, the runway threshold is referenced from the 1-mile (1609-meter) marker to account for those landings that touched down short of the intended point.

Figure 14 shows the frequency distribution of the distance from the 1-mile marker to the touchdown point for 94 landings. The greatest number of landings (20.2 percent) occurred in the interval from 5000 feet to 5500 feet (1524 meters to 1676 meters) from the 1-mile marker with the mean at 5447 feet (1660 meters) or 167 feet (51 meters) beyond the 2-mile marker. The probability curve (fig. 15) indicates that 1 out of 100 landings will probably occur at or beyond a point 8750 feet (2667 meters) from the 1-mile marker or 3470 feet (1058 meters) beyond the 2-mile marker.

Slideout Distance

Since the X-15 airplane is equipped with skid-type gear, as future reentry vehicles may be, the slideout distance was analyzed to permit possible later comparisons. Many factors affect the X-15 slideout (ref. 8),

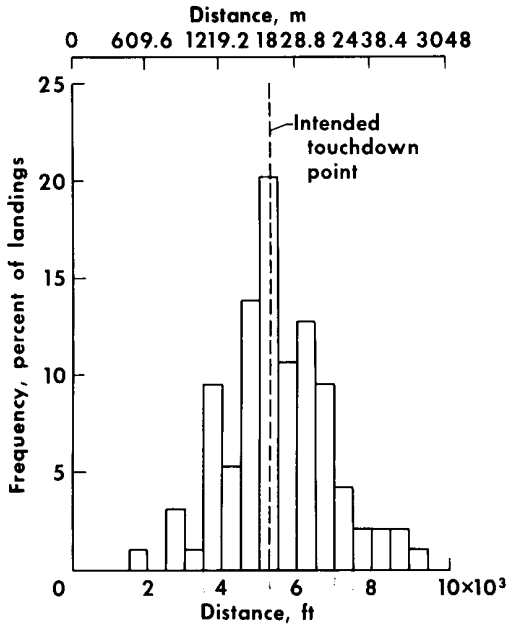


Figure 14.– Histogram of distance to touchdown point from 1-mile marker.

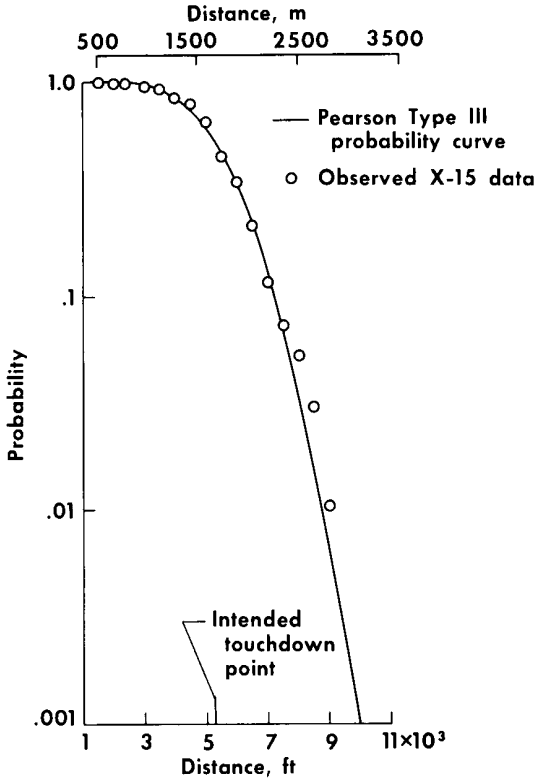


Figure 15.– Probability of equaling or exceeding various values of distance to touchdown point from 1-mile marker.

including lakebed conditions, skid material, skid shape, control inputs, and weight.

The frequency distribution of slideout distances (fig. 16) shows that the greatest percentage of slideouts (14.9) occurred in the interval from 5700 feet to 6000 feet (1737 meters to 1829 meters). The mean slideout distance was 5979 feet (1822 meters). The probability curve (fig. 17) indicates that 1 out of 100 landings will probably include a slideout of 8850 feet (2698 meters) or greater.

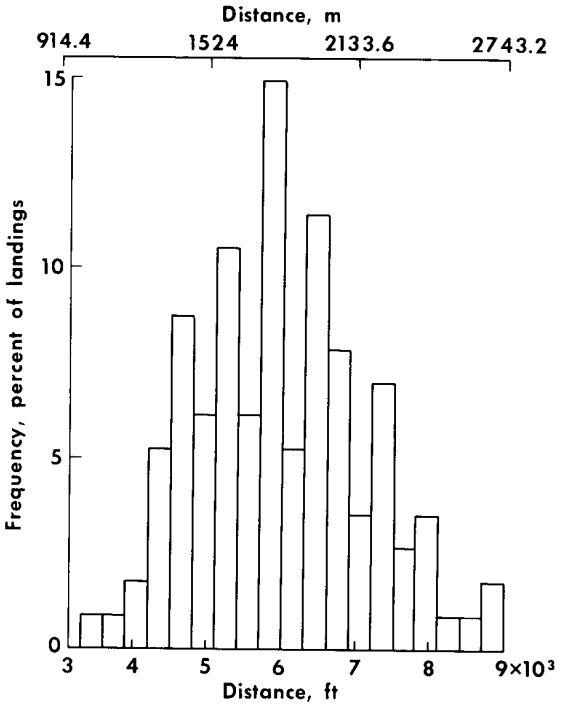


Figure 16.– Histogram of slideout distance.

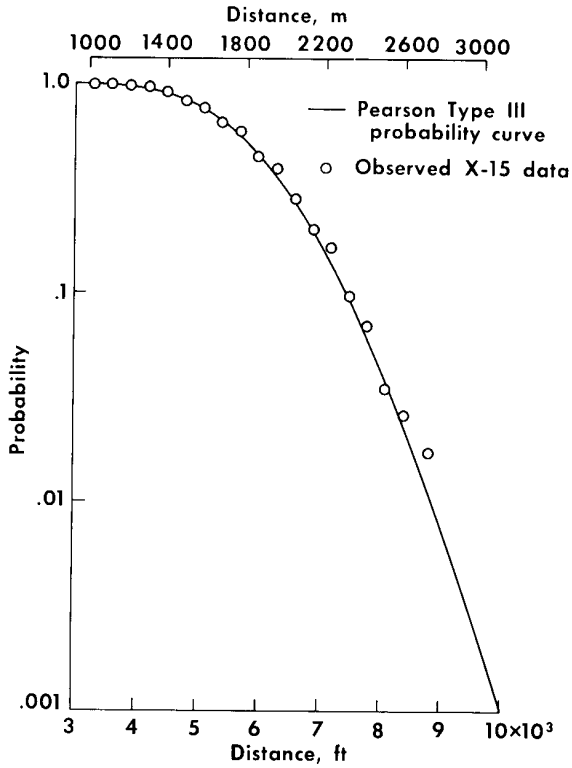


Figure 17.– Probability of equaling or exceeding various values of slideout distance.

The lateral deviation from the initial heading was obtained for a few landings, but the data were insufficient for statistical analysis.

SUMMARY OF RESULTS

An investigation of landing contact conditions for 135 landings of the X-15 airplane on lakebed runways led to the following results:

1. Probability distributions indicate that in 1 out of 100 landings vertical velocity at touchdown will probably equal or exceed 7.4 ft/sec (2.27 m/sec). The mean vertical velocity was 3.4 ft/sec (1.04 m/sec).

2. One landing in 100 is expected to equal or exceed an airspeed at touchdown of 228 knots. The mean airspeed was 190.5 knots.

3. One landing in 100 is expected to equal or exceed a true ground speed at touchdown of 234 knots. The mean true ground speed was 193.0 knots.

4. Probability distributions of rolling velocity indicate that in 1 landing in 100 the vehicle will be rolling in the direction of the first skid to contact at a rate of 6.6 deg/sec (0.114 rad/sec) or at 6.3 deg/sec (0.110 rad/sec) away from the first skid to contact. The mean rolling velocities toward and away from the first skid to contact were 1.77 deg/sec (0.031 rad/sec) and 1.47 deg/sec (0.026 rad/sec), respectively.

5. A roll angle of 3.92° (0.068 rad) will likely be equaled or exceeded once in 100 landings. The mean roll angle was 1.4° (0.024 rad).

6. One in 100 landings will occur at or beyond a point 3470 feet (1058 meters) from the intended touchdown point. The mean touchdown point was 167 feet (51 meters) beyond the intended point.

7. The probability distribution indicates that 1 landing in 100 will include a slideout of 8850 feet (2698 meters) or greater. The mean slideout distance was 5979 feet (1822 meters).

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., October 26, 1966.
124-07-03-01-24

APPENDIX

DETERMINATION OF PEARSON TYPE III PROBABILITY CURVE

A detailed discussion of the Pearson Type III probability curve used in analyzing the data in this paper is presented in reference 9. The purpose of this appendix is simply to describe the mechanics of computing the Pearson Type III curve, which provides a consistent mechanical system of fairing data so that the results can be considered to be on a comparable basis.

The first step is to tabulate the individual measurements, determine the class interval, and calculate the frequency of occurrence for each interval.

The next step is to determine the first moment μ_1' (the arithmetic mean of the measurements), the second moment μ_2' (the arithmetic mean of the squares of the measurements), and the third moment μ_3' (the arithmetic mean of the cubes of the measurements).

The standard deviation S is then determined from

$$\mu_2 = \mu_2' - (\mu_1')^2$$

and

$$S = \sqrt{\mu_2}$$

The skewness of the sample α is determined from

$$\mu_3 = \mu_3' - 3\mu_1'\mu_2' + 2(\mu_1')^3$$

and

$$\alpha = \frac{\mu_3}{S\mu_2}$$

Next, the standard statistical unit t is computed from

$$t = \frac{X_i - \bar{X}}{S}$$

where

X_i = variable X

and

$$\overline{X} = \text{arithmetic mean of } X_i$$

Probability charts for the Pearson Type III curve are included in references 10 and 11. By entering the chart at the proper values of skewness and standard statistical unit t, the probability can be read.

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TABLE I. – VALUES OF CONTACT CONDITIONS AND OTHER PERTINENT DATA FOR LANDINGS OF THE X-15

Flight number (a)	Landing weight, lb (kg)	Wind conditions		Vertical velocity, ft/sec (m/sec)	Velocity at touchdown, KIAS	True ground speed at touchdown, knots	Rolling velocity, deg/sec (rad/sec) (d)	Roll angle, deg (rad)	Touchdown distance from 1-mile mark, ft (m)	Slideout distance, ft (m)
		Velocity, knots	Direction							
1-1-5	13,324 (6043.6)	Calm[b]	-----	2.0 (0.61)	153	168	5.21 (0.091) (A)	---- ------	---- -------	4760 (1450.8)
1-2-7	13,988 (6344.8)	Calm	W	4.8 (1.46)	189	168	.69 (.012) (A)	---- ------	---- -------	6531 (1990.6)
1-3-8	14,564 (6606.0)	21	SW	6.5 (1.98)	214	238	1.43 (.025) (A)	---- ------	---- -------	7228 (2203.0)
1-4-9	14,641 (6641.0)	Calm	-----	5.0 (1.52)	174	184	.29 (.005) (A)	---- ------	---- -------	4714 (1436.8)
1-5-10	14,610 (6626.9)	18	SW	4.5 (1.37)	180	163	---- ------ ---	---- ------	---- -------	4148 (1264.3)
1-6-11	14,233 (6455.9)	Calm	N	1.0 (.30)	189	192	3.44 (.060) (A)	---- ------	---- -------	4920 (1499.6)
1-7-12	14,790 (6708.5)	23	W-SW	1.0 (.30)	193	198	3.78 (.066) (T)	---- ------	---- -------	5420 (1652.0)
1-8-13	14,444 (6551.6)	19	N-NE	4.5 (1.37)	173	190	1.09 (.019) (T)	---- ------	---- -------	5710 (1740.4)
1-9-17	14,838 (6730.3)	7	S	2.0 (.61)	185	190	1.15 (.020) (A)	---- ------	---- -------	5280 (1609.3)
1-10-19	14,318 (6494.5)	4	S	1.5 (.46)	198	205	.29 (.005) (A)	---- ------	---- -------	5940 (1810.5)
1-11-21	14,411 (6536.6)	Calm	-----	3.0 (.91)	192	207	.06 (.001) (A)	---- ------	---- -------	6388 (1947.0)
1-12-23	14,758 (6694.0)	Calm	SW	3.5 (1.07)	181	188	---- ------ ---	---- ------	---- -------	5887 (1794.3)
1-13-25	14,859 (6739.8)	Calm	-----	4.5 (1.37)	196	205	2.12 (.037) (A)	---- ------	---- -------	6837 (2083.9)
1-14-27	14,601 (6622.8)	5	E	5.5 (1.68)	180	185	.57 (.010) (A)	---- ------	---- -------	4778 (1456.3)
1-15-28	14,670 (6654.1)	Calm	-----	3.5 (1.07)	182	191	---- ------ ---	---- ------	---- -------	5310 (1618.4)
1-16-29	14,450 (6554.3)	19	E-NE	2.5 (.76)	195	216	.57 (.010) (T)	---- ------	---- -------	6150 (1874.5)
1-17-30	14,584 (6615.1)	Calm	N	4.5 (1.37)	209	212	---- ------ ---	---- ------	---- -------	6553 (1997.3)
1-18-31	14,559 (6603.8)	Calm	-----	1.5 (.46)	176	182	2.01 (.035) (A)	---- ------	---- -------	4646 (1416.1)
1-19-32	14,586 (6616.0)	4	E	2.0 (.61)	---	---	---- ------ ---	---- ------	---- -------	6300 (1920.2)
1-20-35	14,722 (6677.7)	Calm	S	4.5 (1.37)	210	212	1.15 (.020) (A)	---- ------	---- -------	7600 (2316.4)
1-21-36	14,754 (6692.2)	5	NE	3.0 (.91)	183	187	.57 (.010) (A)	3.5 (0.061)	---- -------	5781 (1762.0)
1-22-37	15,015 (6810.6)	12	SW	5.5 (1.68)	196	195	1.15 (.020) (A)	.10 (.002)	6072 (1850.7)	5230 (1594.1)
1-23-39	14,997 (6802.4)	Calm	N-NE	.5 (.15)	204	213	.17 (.003) (T)	---- ------	6864 (2092.1)	5643 (1719.9)
1-24-40	14,658 (6648.7)	Calm	-----	2.5 (.76)	---	---	3.44 (.060) (A)	---- ------	4938 (1505.1)	6462 (1969.6)
1-25-44[c]	15,515 (7037.4)	7	E	5.5 (1.68)	---	205	---- ------ ---	1.8 (.031)	---- -------	7390 (2252.4)
1-26-46	14,500 (6577.0)	8	SW	3.8 (1.16)	190	---	---- ------ ---	---- ------	4850 (1478.2)	4760 (1450.8)
1-27-48	14,574 (6610.6)	Calm	-----	--- -----	---	176	---- ------ ---	3.1 (.054)	4580 (1395.9)	6600 (2011.6)
1-28-49	14,911 (6763.4)	Calm	-----	3.0 (.91)	187	187	.80 (.014) (A)	2.0 (.035)	7390 (2252.4)	5810 (1770.8)
1-29-50	14,924 (6769.3)	Calm	SW	1.5 (.46)	208	208	.80 (.014) (A)	2.65 (.046)	6330 (1929.3)	7380 (2249.4)
1-30-51	14,371 (6518.5)	Calm	-----	1.5 (.46)	192	192	3.95 (.069) (T)	2.0 (.035)	4225 (1287.7)	5550 (1691.6)
1-31-52	14,573 (6610.1)	Calm	-----	3.0 (.91)	210	---	.86 (.015) (A)	.8 (.014)	6600 (2011.6)	5810 (1770.8)
1-32-53	14,721 (6677.2)	Calm	-----	2.8 (.85)	164	145	.92 (.016) (T)	3.2 (.056)	5600 (1706.8)	6600 (2011.6)
1-33-54	14,981 (6795.2)	Calm	-----	5.3 (1.62)	204	218	---- ------ ---	.7 (.012)	6600 (2011.6)	5808 (1770.2)
1-34-55	14,681 (6659.1)	28	W-SW	3.0 (.91)	187	155	---- ------ ---	1.45 (.025)	---- -------	4012 (1222.8)
1-35-56	14,624 (6633.3)	Calm	-----	3.0 (.91)	187	197	.34 (.006) (A)	1.80 (.031)	4580 (1395.9)	6864 (2092.1)
1-36-57	14,846 (6733.9)	Calm	-----	2.7 (.82)	216	217	.97 (.017) (T)	.70 (.012)	3880 (1182.6)	5280 (1609.3)
1-37-59	14,888 (6753.0)	8	S-SE	.5 (.15)	225	217	2.75 (.048) (T)	7.0 (.122)	4680 (1426.4)	---- -------
1-38-61	14,899 (6758.0)	Calm	-----	3.0 (.91)	207	213	.46 (.008) (T)	1.0 (.018)	5265 (1604.7)	---- -------
1-39-63	14,811 (6718.1)	Calm	-----	2.8 (.85)	175	193	.34 (.006) (T)	1.3 (.023)	4910 (1496.5)	---- -------
1-40-64	14,989 (6798.8)	Calm	----	4.0 (1.22)	178	177	2.06 (.036) (T)	.6 (.010)	4550 (1386.8)	---- -------
1-41-65	14,860 (6740.3)	15	SW	--- -----	178	171	.86 (.015) (A)	.1 (.002)	4836 (1474.0)	---- -------

[a] First term is number of X-15 airplane; second term is number of free flights for that airplane; third term is number of X-15/B-52 missions completed for the airplane.

[b] "Calm" denotes variable from 0 to 3 knots.

[c] Emergency landing.

[d] (A) and (T) denote away from and toward first skid to contact, respectively.

TABLE I. – VALUES OF CONTACT CONDITIONS AND OTHER PERTINENT DATA FOR LANDINGS OF THE X-15 - Continued

Flight number (a)	Landing weight, lb (kg)	Wind conditions		Vertical velocity, ft/sec (m/sec)	Velocity at touchdown, KIAS	True ground speed at touchdown, knots	Rolling velocity, deg/sec (rad/sec) (d)	Roll angle, deg (rad)	Touchdown distance from 1-mile mark, ft (m)	Slideout distance, ft (m)
		Velocity, knots	Direction							
1-42-67	14,605 (6624.6)	2	W-SW	1.6 (.49)	192	148	.97 (.017) (T)	.4 (.007)	3696 (1126.5)	7392 (2253.0)
1-43-69	14,635 (6638.2)	13	NE	4.2 (1.28)	192	---	2.69 (.047) (T)	7.0 (.122)	3280 (999.7)	---- -------
1-44-70	14,467 (6562.0)	Calm[b]	-----	2.0 (.61)	184	189	.29 (.005) (T)	.4 (.007)	4699 (1432.2)	6336 (1931.2)
1-45-72	14,983 (6796.1)	4	S-SW	2.0 (.61)	198	198	1.09 (.019) (T)	---- ------	---- -------	7920 (2414.0)
1-46-73	14,997 (6802.4)	Calm	-----	2.0 (.61)	192	195	.23 (.004) (T)	1.3 (.023)	4280 (1304.5)	---- -------
1-47-74	14,968 (6789.3)	9	S-SW	1.0 (.30)	222	175	3.84 (.067) (A)	1.1 (.019)	5000 (1524.0)	---- -------
1-48-75	15,111 (6854.1)	Calm	-----	4.0 (1.22)	184	185	.46 (.008) (A)	1.3 (.023)	---- -------	---- -------
1-49-77	14,937 (6775.2)	12	SE	4.3 (1.31)	195	186	1.03 (.018) (A)	---- ------	---- -------	---- -------
1-50-79	15,068 (6834.6)	10	E	1.6 (.49)	178	196	2.69 (.047) (A)	.97 (.017)	3889 (1185.3)	7251 (2210.1)
1-51-81	15,087 (6843.3)	5	E	3.4 (1.04)	189	198	1.83 (.032) (T)	---- ------	5803 (1768.7)	6549 (1996.1)
1-52-85	15,062 (6831.9)	Calm	-----	1.6 (.49)	195	197	1.83 (.032) (T)	1.02 (.018)	3996 (1217.9)	7137 (2175.3)
1-53-86	14,697 (6666.4)	-----	S-SW	3.2 (.98)	195	184	.40 (.007) (T)	.72 (.013)	5627 (1715.1)	5892 (1795.8)
1-54-88	14,817 (6720.8)	5	Variable	--- -----	184	---	5.62 (.098) (T)	.70 (.012)	8710 (2654.8)	4700 (1432.5)
1-55-89	14,712 (6673.2)	6	E	2.3 (.70)	---	---	3.15 (.055) (A)	3.35 (.058)	3724 (1135.0)	6105 (1860.8)
2-1-3	13,984 (6343.0)	9	SW	5.0 (1.52)	184	203	.74 (.013) (A)	---- ------	---- -------	5560 (1694.6)
2-2-6	14,165 (6425.1)	Calm	NW	7.7 (2.35)	180	191	1.15 (.020) (A)	---- ------	---- -------	4252 (1296.0)
2-3-9[c]	15,183 (6886.8)	18	NW	9.5 (2.90)	161	145	.46 (.008) (T)	---- ------	---- -------	1561 (475.7)
2-4-11	15,062 (6831.9)	4	SW	6.5 (1.98)	188	185	3.21 (.056) (T)	---- ------	---- -------	5734 (1747.7)
2-5-12	14,798 (6712.2)	Calm	-----	3.6 (1.10)	185	183	1.15 (.020) (T)	---- ------	---- -------	4669 (1423.1)
2-6-13	14,619 (6631.0)	9	N-NE	2.5 (.76)	192	201	1.83 (.032) (A)	---- ------	---- -------	6073 (1851.0)
2-7-15	14,394 (6528.9)	Calm	N-NE	2.5 (.76)	193	193	2.75 (.048) (A)	---- ------	---- -------	5938 (1809.9)
2-8-16	14,583 (6614.7)	Calm	-----	3.5 (1.07)	185	198	.69 (.012) (T)	---- ------	---- -------	5625 (1714.5)
2-9-18	14,469 (6562.9)	Calm	SE	4.0 (1.22)	160	161	.29 (.005) (A)	---- ------	---- -------	4330 (1319.7)
2-10-21	14,419 (6540.3)	5	NE	5.0 (1.52)	156	165	2.86 (.050) (A)	---- ------	---- -------	5042 (1536.8)
2-11-22	14,486 (6570.7)	Calm	-----	4.5 (1.37)	187	196	3.55 (.062) (A)	---- ------	---- -------	6574 (2003.7)
2-12-23	14,381 (6523.0)	17	NE	5.5 (1.68)	181	203	---- ------ ---	---- ------	---- -------	6600 (2011.6)
2-13-26	14,501 (6577.5)	10	N-NE	4.0 (1.22)	180	182	.86 (.015) (T)	1.2 (.021)	4224 (1287.4)	5340 (1627.6)
2-14-28	14,871 (6745.3)	Calm	SE	2.9 (.88)	---	---	---- ------ ---	---- ------	6230 (1898.9)	6531 (1990.6)
2-15-29	14,447 (6553.0)	20	W-SW	3.7 (1.13)	189	171	2.58 (.045) (A)	---- ------	5280 (1609.3)	3778 (1151.5)
2-16-31	14,567 (6607.4)	Calm	E	2.3 (.70)	189	201	.34 (.006) (A)	---- ------	6600 (2011.6)	6761 (2060.7)
2-17-33	14,945 (6778.9)	14	S-SW	5.0 (1.52)	180	175	---- ------ ---	---- ------	5180 (1578.8)	4646 (1416.1)
2-18-34	14,610 (6626.9)	10	S-SW	2.8 (.83)	186	196	---- ------ ---	1.2 (.021)	5080 (1548.3)	4490 (1368.5)
2-19-35	14,654 (6646.9)	9	S-SW	2.5 (.76)	179	171	---- ------ ---	.7 (.012)	3780 (1152.1)	4418 (1346.6)
2-20-36	14,692 (6664.1)	7	S	2.0 (.61)	175	180	.23 (.004) (A)	.3 (.005)	2904 (885.1)	4325 (1318.2)
2-21-37	14,600 (6622.4)	Calm	S	4.5 (1.37)	179	179	1.72 (.030) (A)	---- ------	3960 (1207.0)	5280 (1609.3)
2-22-40	14,891 (6754.4)	11	W	.5 (.15)	196	202	1.32 (.023) (A)	1.6 (.028)	7380 (2249.4)	5800 (1767.8)
2-23-43	14,968 (6789.3)	Calm	-----	2.2 (.67)	184	178	4.35 (.076) (T)	1.2 (.021)	5375 (1638.3)	5810 (1770.8)
2-24-44	14,959 (6785.2)	9	SW	4.1 (1.25)	191	188	1.09 (.019) (T)	1.65 (.029)	---- -------	5820 (1773.9)
2-25-45	14,960 (6785.7)	Calm	-----	1.8 (.55)	195	198	2.29 (.040) (T)	---- ------	6330 (1929.3)	7150 (2179.3)
2-26-46	15,091 (6845.1)	10	S	1.8 (.55)	175	181	4.58 (.080) (T)	.75 (.013)	4980 (1517.9)	4580 (1395.9)
2-27-47	15,021 (6813.3)	Calm	-----	2.3 (.70)	181	175	2.18 (.038) (T)	.65 (.011)	4872 (1484.9)	5020 (1530.0)
2-28-48	14,983 (6796.1)	18-26	SW	2.2 (.67)	200	---	2.06 (.036) (T)	3.1 (.054)	4872 (1484.9)	6600 (2011.6)
2-29-50	15,102 (6850.1)	Calm	-----	--- -----	187	---	2.01 (.035) (T)	---- ------	5280 (1609.3)	6870 (2093.9)
2-30-51	14,953 (6782.5)	Calm[b]	-----	4.0 (1.22)	173	186	1.72 (.030) (A)	.3 (.005)	5808 (1770.2)	6340 (1932.4)
2-31-52[c]	15,982 (7249.2)	4	SE	3.9 (1.19)	256	251	.40 (.007) (T)	---- ------	---- -------	---- -------
2-32-55	15,991 (7253.3)	Calm	SW	--- -----	---	---	---- ------ ---	1.0 (.017)	2542 (774.8)	---- -------
2-33-56	15,522 (7040.6)	Calm	-----	--- -----	211	164	3.90 (.068) (T)	1.68 (.029)	5280 (1609.3)	5365 (1635.2)
2-34-57	15,798 (7165.8)	Calm	-----	2.6 (.79)	178	205	1.38 (.024) (A)	.12 (.002)	4333 (1320.6)	6056 (1845.8)
2-35-60	15,855 (7191.6)	Calm	-----	1.8 (.55)	192	---	4.87 (.085) (A)	.19 (.003)	7920 (2414.0)	8968 (2733.4)
2-36-63	15,947 (7233.3)	Calm	-----	--- -----	225	---	---- ------ ---	.39 (.007)	1685 (513.5)	7627 (2324.7)

TABLE I. – VALUES OF CONTACT CONDITIONS AND OTHER PERTINENT DATA FOR LANDINGS OF THE X-15 - Concluded

Flight number (a)	Landing weight, lb (kg)	Wind conditions		Vertical velocity, ft/sec (m/sec)	Velocity at touchdown, KIAS	True ground speed at touchdown, knots	Rolling velocity, deg/sec (rad/sec) (d)	Roll angle, deg (rad)	Touchdown distance from 1-mile mark, ft (m)	Slideout distance, ft (m)
		Velocity, knots	Direction							
3-1-2	14,723 (6678.2)	Calm	-----	2.0 (.61)	181	176	---- ------ ---	2.1 (.037)	5530 (1685.5)	6200 (1889.7)
3-2-3	14,303 (6487.6)	Calm	-----	2.5 (.76)	191	---	---- ------ ---	.65 (.011)	5250 (1600.2)	6340 (1932.4)
3-3-7	14,307 (6489.5)	Calm	-----	2.5 (.76)	---	---	---- ------ ---	---- ------	6500 (1981.2)	6450 (1965.9)
3-4-8	14,286 (6479.9)	12	N-NW	7.3 (2.23)	165	---	---- ------ ---	---- ------	---- ------	5104 (1555.6)
3-5-9	14,653 (6646.4)	17	W	1.0 (.30)	188	181	.29 (.005) (A)	1.5 (.026)	5808 (1770.2)	5810 (1770.8)
3-6-10	14,553 (6601.0)	Calm	-----	6.2 (1.89)	183	162	.57 (.010) (T)	.90 (.016)	5808 (1770.2)	5280 (1609.3)
3-7-14	14,420 (6540.7)	Calm	-----	3.0 (.91)	198	201	---- ------ ---	2.2 (.038)	5330 (1624.5)	5030 (1533.1)
3-8-16	14,558 (6603.3)	-----	-----	--- -----	189	---	.29 (.005) (A)	1.0 (.017)	5280 (1609.3)	---- ------
3-9-18	14,246 (6461.8)	6	SW	4.0 (1.22)	183	---	---- ------ ---	2.0 (.035)	6340 (1932.4)	5280 (1609.3)
3-10-19	14,492 (6573.4)	13-22	-----	6.8 (2.07)	---	---	.40 (.007) (A)	2.5 (.044)	5280 (1609.3)	---- ------
3-11-20	14,411 (6536.6)	Calm	-----	.5 (.15)	212	223	---- ------ ---	.30 (.005)	6336 (1931.2)	7920 (2414.0)
3-12-22	14,491 (6572.9)	-----	-----	.5 (.15)	188	188	6.88 (.120) (A)	.65 (.011)	5295 (1613.9)	7286 (2220.7)
3-13-23	14,562 (6605.1)	Calm	-----	--- -----	178	192	---- ------ ---	2.2 (.038)	6860 (2090.9)	7400 (2255.5)
3-14-24	14,709 (6671.8)	Calm	-----	2.0 (.61)	190	202	.57 (.010) (T)	1.2 (.021)	5257 (1602.3)	7392 (2253.0)
3-15-25	15,032 (6818.3)	15-30	S-SW	3.6 (1.10)	222	227	.06 (.001) (T)	1.7 (.030)	3440 (1048.5)	8787 (2678.2)
3-16-26	14,926 (6770.2)	4	E-NE	3.7 (1.13)	216	211	.23 (.004) (A)	1.8 (.031)	6336 (1931.2)	7867 (2397.8)
3-17-28	14,937 (6775.3)	15-23	W-SW	3.8 (1.16)	222	224	1.32 (.023) (A)	1.35 (.024)	5380 (1639.8)	7709 (2349.7)
3-18-29	14,795 (6710.8)	Calm	-----	.5 (.15)	---	---	---- ------ ---	---- ------	5430 (1655.0)	5300 (1615.4)
3-19-30	14,702 (6668.6)	8	SW	3.3 (1.01)	207	207	.29 (.005) (A)	2.7 (.047)	5405 (1647.4)	7920 (2414.0)
3-20-31	14,918 (6766.6)	11-24	SW	4.5 (1.37)	222	211	.80 (.014) (A)	1.85 (.032)	6180 (1883.6)	---- ------
3-21-32	14,625 (6633.7)	Calm	-----	4.0 (1.22)	198	196	.69 (.012) (A)	1.25 (.022)	6280 (1914.1)	---- ------
3-22-36	14,631 (6636.4)	10	S	5.5 (1.68)	---	196	.46 (.008) (A)	.55 (.010)	4980 (1517.9)	---- ------
3-23-39	14,943 (6777.9)	-----	-----	4.0 (1.22)	198	204	.63 (.011) (T)	.20 (.003)	8280 (2523.7)	8170 (2490.2)
3-24-41	15,160 (6876.4)	2	W-SW	6.4 (1.95)	160	164	.17 (.003) (A)	3.1 (.054)	6600 (2011.6)	4488 (1367.9)
3-25-42	14,912 (6763.9)	Calm	-----	4.3 (1.31)	181	175	.11 (.002) (A)	2.4 (.042)	6705 (2043.6)	5702 (1737.9)
3-26-43	15,050 (6826.5)	2	S	5.4 (1.65)	184	208	2.35 (.041) (A)	---- ------	7656 (2333.5)	4805 (1464.5)
3-27-44	15,067 (6834.2)	Calm	-----	3.9 (1.19)	184	193	5.21 (.091) (T)	1.05 (.018)	9240 (2816.3)	5204 (1586.1)
3-28-47	14,760 (6694.9)	Calm	-----	3.0 (.91)	184	187	1.72 (.030) (A)	---- ------	6980 (2127.5)	5808 (1770.2)
3-29-48[c]	14,937 (6775.2)	Calm	-----	4.2 (1.28)	184	181	5.39 (.094) (T)	1.5 (.026)	---- ------	3520 (1072.8)
3-30-50	15,034 (6819.2)	15	N-NE	1.5 (.46)	213	159	.63 (.011) (A)	.55 (.010)	---- ------	---- ------
3-31-52	14,983 (6796.1)	5	S	2.3 (.69)	195	223	1.83 (.032) (T)	.40 (.007)	---- ------	8638 (2632.8)
3-32-53	15,175 (6883.2)	-----	-----	5.0 (1.52)	195	224	.06 (.001) (T)	.44 (.008)	4013 (1223.1)	7128 (2172.6)
3-33-54	14,926 (6770.2)	12	W	5.9 (1.80)	201	208	4.70 (.082) (A)	.90 (.016)	5580 (1700.7)	---- ------
3-34-55	14,898 (6757.5)	Calm	-----	4.4 (1.34)	192	175	.29 (.005) (A)	.44 (.008)	7128 (2172.6)	4646 (1416.1)
3-35-57	14,889 (6753.5)	6	W-SW	2.6 (.79)	189	226	---- ------ ---	2.66 (.046)	4380 (1335.0)	5720 (1743.4)
3-36-59	15,552 (7054.2)	Calm[b]	-----	2.8 (.85)	210	217	2.64 (.046) (A)	2.58 (.045)	3880 (1182.6)	7030 (2142.7)
3-37-60	15,066 (6833.7)	Calm	-----	2.3 (.70)	174	203	.11 (.002) (T)	1.15 (.020)	3875 (1181.1)	4902 (1494.1)
3-38-61	15,036 (6820.1)	16-27	W-SW	2.9 (.88)	207	217	.97 (.017) (A)	1.02 (.018)	8002 (2439.0)	6257 (1907.1)
3-39-62	14,749 (6689.9)	Calm	-----	4.5 (1.37)	192	187	.57 (.010) (A)	.11 (.002)	5316 (1620.3)	5418 (1651.4)
3-40-63	15,048 (6825.6)	Calm	-----	1.9 (.58)	189	191	1.72 (.030) (A)	1.57 (.027)	7029 (2142.4)	6757 (2059.5)
3-41-64	------ -------	Calm	-----	.5 (.15)	186	173	.46 (.008) (A)	.02 (.000)	8710 (2654.8)	5076 (1547.1)
3-42-65	------ -------	Calm	-----	2.0 (.61)	186	204	---- ------ ---	1.43 (.025)	6269 (1910.7)	6580 (2005.5)
3-43-66	------ -------	10	W-SW	2.5 (.76)	198	220	---- ------ ---	2.06 (.036)	6418 (1956.2)	5517 (1681.5)
3-44-67	------ -------	Calm	-----	5.4 (1.65)	172	216	---- ------ ---	3.31 (.058)	5610 (1709.9)	5643 (1719.9)

TABLE II.- VALUES OF STATISTICAL PARAMETERS FOR THE X-15 LANDING CONTACT CONDITIONS

Description	Mean	Standard deviation	Coefficient of skewness
Vertical velocity	3.4 ft/sec (1.04 m/sec)	1.53 ft/sec (0.47 m/sec)	0.412
Indicated airspeed	190.5 knots	14.51 knots	0.345
True ground speed	193.0 knots	18.46 knots	-0.230
Rolling velocity toward first skid to contact	1.77 deg/sec (0.031 rad/sec)	1.585 deg/sec (0.028 rad/sec)	0.983
Rolling velocity away from first skid to contact	1.47 deg/sec (0.026 rad/sec)	1.436 deg/sec (0.025 rad/sec)	1.546
Roll angle	1.40° (0.024 rad)	0.93° (0.016 rad)	0.610
Touchdown distance from 1-mile marker	5447 ft (1660.2 m)	1366.8 ft (416.6 m)	0.106
Slideout distance	5979 ft (1822.3 m)	1139.2 ft (347.2 m)	0.284